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11. From the Author

ON

THE EROSION

OF

VALLEYS AND LAKES;

A

REPLY TO SIR RODERICK MURCHISON'S

ANNIVERSARY ADDRESS TO THE GEOGRAPHICAL
SOCIETY.

BY

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EROSION OF VALLEYS AND LAKES.

AFTER the publication of my memoir "On the Glacial Origin of certain Lakes in the Ice-worn regions of Europe and North America," several eminent British and Continental geologists, and some other persons who have only a general literary acquaintance with physical geology, did me the honour, in special memoirs, or in letters in newspapers, to express opinions that my views were deserving of the strongest opposition. To none of these opponents have I heretofore made any reply, and some of them, I found, were dealt with by men who met their arguments more ably perhaps than I could have done myself. Besides, I considered that if my theory, as I believe, be true, it would be sure in the long run to make its way just in the slow and steady manner it seems to me to be now doing. We all profess to appeal to nature, and "in nature there is no opinion; there is truth in everything that is in nature; and in man alone is error." To those who are not geologists in any practical sense it would never occur to me to reply. Physical geology, in the true meaning of the term, does not exist without a thorough practical acquaintance with, and experience of, rocks of all kinds on a large scale. The man who merely wanders about a country and looks curiously at rocks, without a long course of severe training, has no more scientific right to form a definite opinion as to the causes that brought about the external configuration of the land than the father of a family would have to decide questions in comparative anatomy, because for half his life he had daily carved beef, mutton, pork, fowls, and fish.

Of late, however, an exceedingly authoritative protest against my theory has been entered by Sir Roderick Murchison, in his Anniversary Address to the Geographical Society,—an address issued indeed to the geologists of Europe; for the portion that bears upon icy phenomena has been printed separately for special distribution. It would almost be uncourteous on my part silently to pass over the remarks of one who in his own person has attained the highest honours in the Geological and the Geographical Societies, and who is besides my oldest living geological friend. "As a geologist, with wide experience, the President of

the geographers clearly states his conviction "that my theory of the origin of certain lakes and other theories of denudation connected therewith, are so opposed to obvious facts, that, if his conviction be well founded, the wonder seems to me that any man of weight and knowledge could be found to follow me at all. I may therefore be pardoned if in this instance I depart from the course of leaving the value of my theory to be worked out solely by time.

I have said that Sir Roderick has entered an *authoritative protest*, because, as several persons have remarked to me, so much stress has been laid on the *argumentum ad hominem*, liberally as regards Continental geologists, and more sparingly with American and English names. Indeed, in reading the Address, I was more than once reminded of the observation of one of my opponents, who in the 'Reader' observed to this effect, "that Professor Desor entirely disagrees with Professor Ramsay—how can he do otherwise? for Desor has lived among glaciers all his life." In like manner Studer and Escher von der Linth, "by numerous appeals to nature," Gastaldi, De Mortillet, and many more are all arrayed in opposition to the theory, the presumption being that the chances are therefore infinitely against it, and I must needs be wrong because they are so eminent, and some of them have lived so long among the Alps. For, differing from them, how is it likely that a man can be right who has only explored the Alps five or six times with a special object, even though he may have spent five-and-twenty years on subjects allied to or identical with it? Such is the general impression produced, not on myself alone, by many of Sir Roderick's remarks. I have no objection to this kind of argument; it is so old in the history of science that its value is understood. To compare great things with our small matter, Copernicus and Galileo experienced it, Hutton and Playfair knew it well; the most eminent geologists were for long deaf to the voice of William Smith, let him charm ever so wisely; and Agassiz himself, in glacial geology, had among his chief opponents distinguished seniors, some of whom even now only hesitatingly follow him. It is easy to "appeal to nature," but the language of her reply is not always to be understood merely by long poring on her face; and it generally happens that many an abortive effort is made before some happy accident reveals the key.

In my original memoir, when discussing the origin of the lake-basins, I found it necessary in some degree to treat of disturbances of rocks in general. Accordingly, Sir Roderick very properly regards the question as one not merely of lakes, but as involving his belief "with the vast majority of practical geologists, that the irregularities of the surface of the Alps have been primarily

* Geological Magazine, No. 3, p. 127.

caused by dislocations and denudations ;” and again, that “until lately geologists seemed so be generally agreed that most of the numerous deep openings and depressions which exist in all lofty mountains were *primarily due to cracks which took place during the various movements which each chain has undergone at various periods,*” &c. The meaning of this, I conceive to be, that mountain valleys lie in lines of curvature, dislocation, and fracture, and that the mountains on each side of them are mountains, far less because of denudation than by reason of operations of fracture and dislocation. Therefore important lakes that fill true rock-basins lie only in lines of fracture, or else, as in the myriad lakes of North America, in hollows of wider dislocation somewhat aided by subsequent denudations.

Every reasoning mind respects authority when it bears on questions that have been reduced to demonstration ; but this is precisely what has not been done with respect to the origin of *special* Alpine lakes and valleys by those whose main argument is disturbance of strata. Assertions and crude ideas in all kinds of books and papers are “as plenty as blackberries ;” but for clear demonstrations—none are given. Nor does Sir Roderick either attempt or point to any when he says that in the Alps he “long ago came to the conclusion that the chief cavities, vertical precipices, and subtending deep, narrow gorges, have been *originally* determined by movements and openings of the crust, whether arranged in anticlinal or synclinal lines, or not less frequently modified by great transversal or lateral breaks, at right angles to the longitudinal or main folds of elevation or depression.” Now in my paper I gave six stratigraphical reasons to show why the lakes do not lie in hollows of disturbance, and then pointed to ice as the only remaining agent by which they could be formed, thus attempting to reduce the matter as nearly as I could to a demonstration ; and what I want is an attempt at demonstration in return. But where is the proof beyond the general assertion and impression that craggy-sided mountains and valleys prove dislocations which gape. If they were mere close or nearly close fractures and denudation did the rest, the argument is equally in favour of my view ; for valleys which have been scooped out by denudation often necessarily coincide with lines of fracture, a proposition obvious to every geologist. But I want the proof that the Alpine valleys are dislocations. Let any one go into them and prove it in numerous cases, with his geological map in his hand, by the arrangement of the rocks on either side, and by the fracture or fault visible, or otherwise certainly demonstrable in the bottom. Where are these valley faults, whose name ought to be legion, marked in the best geological maps of Switzerland ? If they exist, they remain yet to be indicated in definite lines ; for indeed none know better than the

many eminent geologists of Switzerland and the north of Italy, for whom and for whose work I have the highest respect, that the geological map of their country is as yet but an admirable sketch, and in all probability will remain so till their governments authorize more general and uniform painstaking surveys. When this is done, and when all the faults and curvatures possible *are actually laid down, and when geological sections on a true scale* have been run across the Alps, it will then be possible to reason with precision on the denudation of the mountains; and it will be found (what is well known now) that before the present surface of the valleys saw the light, vast piles of strata, as in Wales, have been removed by denudation, and the valleys were formed long after the latest important disturbances of the strata took place.

And now to prove that I also respect authority, let me quote from books of immortal repute; and surely those who reverence authority most, will not disdain that of Hutton and Playfair. What say the father of physical geology and his great disciple? "If," says Hutton, reasoning on this subject, "the valley was made for the rain by any other natural cause, either we should tell by what means this work had been performed, or all reasoning on the subject is at end, *and fancy substituted in its place*. If, again, the river be considered as the means employed by nature in making this valley, then all the solid parts between the bounding mountains must have been removed." Again, reasoning on the weathering and erosion that *originated* the pyramids on and around Mont Blanc, he observes, "It is true, indeed, that geologists have everywhere imagined to themselves great events, or powerful causes, by which these changes in the earth should be brought about in a short space of time; but they are under a double deception; *first*, with regard to time, which is unlimited*, whereas they want to explain appearances by a cause acting in a limited time; *secondly*, with regard to operation, their supposition of a great *débâcle* is altogether incompetent for the end required." Again, arguing on the approximately horizontal gneissic strata of the neighbourhood of Monte Rosa, he shows that the great isolated peaks have been separated by "the greatest degradation, in being wasted by the hand of time. . . . Here," he says, "is nothing but a truth that may almost everywhere be perceived" if we had only faculties to perceive it.

Again, reasoning on strata that correspond on opposite sides of valleys, Playfair, in the Huttonian Illustrations, says, "there is no man, however little addicted to geological speculations, who does not immediately acknowledge that the mountain was once continued quite across the place in which the river now flows; and, if he ventures to reason concerning the cause of so wonder-

* In the original, "limited." This is an evident misprint.

ful a change, he ascribes it [in the modern fashion] to some great convulsion of nature, which has torn the mountain asunder and opened a passage for the waters. It is only the philosopher, who has deeply meditated on the effects which action long continued is able to produce, and on the simplicity of the means which nature employs in all her operations, who sees in this nothing but the gradual working of a stream, that once flowed over the top of the ridge which it now so deeply intersects, and has cut its course through the rock, in the same way, and almost with the same instrument, by which the lapidary divides a block of marble or granite." And in the Alps (p. 122) he shows that "the sharp peaks of the granite mountains . . . but mark so many epochs in the progress of decay," while the loftiness of the harder peaks is due not to mere upheaval but to the circumstance "that the waste and *detritus* to which all things are subject will not allow soft and weak substances to remain long in an exposed and elevated situation." "Thus, with Dr. Hutton (p. 126), we shall be disposed to consider those great chains of mountains, which traverse the surface of the globe, as cut out of masses vastly greater, and more lofty than anything that now remains." I could multiply sentences of this kind from the writings of these great philosophers; but enough has been said to recall to memory the fact that before the present race of "practical geologists" had written a line, men of rare knowledge, keen sagacity, and the highest intellectual powers, by appeals to nature already held those views which some of their degenerate descendants have so readily repudiated, but to which a younger school show strong symptoms of returning. I doubt also if some of the Swiss and Italian geologists will be quite content to stand godfathers to the opinion that the Alpine valleys generally are apt to lie in lines of mere curvature or fracture, whether close or gaping; but without further authority than that of personal conversation it would be improper to quote their names.

Unless I were to write a special elementary treatise on denudation, enough has now been said to show that the theory of formation of great systems of valleys by erosion in which water and ice are main agents, is not a mere absurdity, and I do not therefore care minutely to analyze the assertions that many of the Alpine rivers "flow in fissures or deep chasms, . . . which water alone never could have opened out;" or again, that the Rhine and the Danube "never could have eroded those deep abrupt gorges through which they here and there flow, and which are manifestly due to original ruptures of the rocks." To the neglected and even half-forgotten school of Hutton and Playfair, and to many expert geologists of the present day whose lives have been spent in practically analyzing the rocky struc-

tures of countries, the *manifest* nature of such "original ruptures" is anything but evident; and I for one believe that the "ruptures" are only manifest to those who accept such hypotheses "without inquiring into what has been the former state of things, or what will be the future"*. To this day there is no error so common, even among geologists, as that which vaguely attributes the form and nature of the present surface-outlines of the earth chiefly to the operation of violent disturbance in recent geological times, not clearly perceiving that the great and small outlines of mountain-chains, of valleys, of river-gorges and of plains are the combined results of an immense number of operations, many of these going back to exceedingly remote periods of geological antiquity, and a great proportion of their details being lost even to probable conjecture.

These operations, however, in the production of scenery mainly resolve themselves into the following series, the parts of which, ever since land and water first existed, may be arranged in any possible combination.

a. *Oscillation with respect to the sea-level of rocks that have or have not been contorted and metamorphosed, accompanied by pauses in oscillation of greater or less duration.*

b. *Great plains of marine denudation.*

c. *Subaërial denudations of all kinds; wearing away of sea-coasts; and in the interior of the country, chemical decompositions, frost, snow, ice, wind, rain, and rivers; modified by height of land, and the various positions, hardness, and other characters of rocks.*

Contortion and metamorphism seem to be essential accompaniments of all great mountain-chains. It may also possibly be proved that in intensely contorted regions mountain-chains are high or low according to the relative antiquity of disturbance, while sometimes the irregular protuberances, as in the Devonian and other rocks of the Rhine and Moselle, have been planed away altogether.

Plains of marine denudation are sure to be inclined at a very low angle if formed during slow depression of the land.

Further, while the sea helps to make bays, the other agents of waste enumerated above cut out all mountain-peaks not volcanic, all the *minor valleys*, in this term including such valleys as those of the Alps, the Highlands, Wales, &c., but not such a valley as the great one that lies between the Alps and the Jura.

Fractures and volcanos, in the production of the great scenic features of continental physical geography, are, as a rule, mere subordinate and subsidiary accidents, the first modifying the effects of denudation by juxtaposition of different kinds of rocks, and the second (which seem to be connected with general elevations) forming accidental mountains, hills, and hilly regions,

* Hutton, vol. ii. p. 257.

which, as in the Andes, may form non-essential parts of mountain-chains.

I shall now make some remarks on what has been said in the Address respecting the action of ice in general, and its share in forming lakes that are true rock-basins in particular, taking these in connexion with other points at issue.

"Before entering on the consideration of the new theory of the power of moving ice," Sir Roderick gives a brief review of the recent progress of Alpine glacial geology, meaning by recent principally those twenty-five or thirty years that have elapsed since Agassiz began to insist not only on the enormous size of the old glaciers of the Alps, but on what is now generally recognized as the true glacial theory. "Granting to the land glacialists their full demand" for the great size of the old glacier of the Rhone, it is stated by Sir Roderick, backed by the authority of Sir Charles Lyell, that there is *nothing* in that fact "which supports the opinion that the deep cavity in which the lake [of Geneva] lies was excavated by ice;" for among other things it is "to be noticed in the case of the Lake of Geneva" that it "trends from E. to W., whilst the detritus and blocks sent forth by the old glacier of the Rhone have all proceeded to the N. and N.N.W., or in direct continuation of the line of march of the glacier which issued from the narrow gorge of the Rhone. By what momentum, then, was the glacier to be so deflected to the west that it could channel or scoop out, on flat ground, the great hollow now occupied by the Lake of Geneva? And, after effecting this wonderful operation, how was it to be propelled upwards from this cavity on the ascent, to great heights on the slopes of the Jura mountains?" The same argument it is stated holds good of the Rhine glacier, which I have attempted to show scooped out the shallow hollow of the Lake of Constance. One would suppose these questions to be so conclusive, that the mere asking is enough, and any opposite views must be absurdities which no man of any sound knowledge could entertain; and yet men are found who do entertain them in part or in whole, even authors of great authority on geological and physical subjects, not only in the three kingdoms, but on the continents of Europe and America. Now with regard to the great old glacier of the Rhine, the sentence bearing on it is so worded that I am unable to make out whether it is implied that in the belief of Sir Roderick Murchison no great glacier issuing from the Upper Rhine valley ever overspread the region around the Lake of Constance, or whether he and M. Escher von der Linth simply at one time could not find signs of a glacier that so "plunged into the flat region on the east and north" (of the Hohe Sentis) "as to have scooped out the cavity in which the lake lies." If the former, then Sir

Roderick's opinion seems to have been formed a long time ago; for, adopting M. Escher's authority, anyone who consults his map of the ancient extension of the Alpine glaciers, will see that he draws an enormous glacier, which issuing from the broad flat valley of the Rhine, tranquilly overspread the country on all sides of the lake, and without the necessity for any plunge, could only have been fed by smaller tributary streams of ice that, if such existed, descended on the northern slopes of the Hohe Sentis*.

In like manner, Sir Roderick is of opinion that the basin of the Lake of Geneva was not scooped out by ice, because "it trends from east to west," or at right angles to the main flow of the glacier—because ice, *per se*, neither has nor has had any excavating power"—because (p. 12) "in valleys with a very slight descent, . . . no erosion whatever takes place, particularly as the bottom of the glacier is usually separated from the subjacent rock or vegetable soil by water arising from the melting of the ice," and because even in gorges "whence the largest glaciers have advanced for ages, we meet with islands of solid rock and little bosses still standing out, even in the midst of the valleys down which the icy stream has swept," and "there is no proof of wide erosion"—and, yet again, because (p. 15) "ice has so much plasticity that it has always moulded itself upon the inequalities of the hard rocks over which it passed," and "has never excavated the lateral valleys, nor even cleared out their old alluvia," and furthermore, in general terms, because ice could not have been propelled up an inclination from the bottom of a lake, let the angle, I presume, be ever so small.

Now the east and west course of the lake is here treated as if the glacier of the Rhone which overspread it were the only glacier which helped to cover the area; but if any one will take the trouble to refer to the map which accompanies my memoir, or, better still, to M. Escher's, he will see that the mass of ice must have been prodigiously swelled by the great tributary glacier of Chamouni, which, descending from Mont Blanc, filled a valley some fifty miles in length, and joined the Rhone glacier near the lower end of the Lake of Geneva. Neither does it require much reasoning to see that during the cold of the glacial epoch all the higher region south of the lake must have maintained its glaciers and filled the valleys that run north; for even now some of the

* I have to apologize to my friend M. Escher von der Linth for not having used his map of the ancient glaciers as my chief authority when my Memoir on the Lakes was read. The first time I saw his map, which was sent me by Principal Forbes of St. Andrews, was after the publication of my memoir. Had I seen it in time, I would certainly have availed myself, in the construction of my sketch map, of the authority of a geologist so accurate and distinguished as Escher von der Linth.

peaks are tipped with perpetual snow. The Rhone glacier had therefore no lack of tributaries to maintain its mass over all the area of the Lake of Geneva, though towards the west, where the glacier thinned away, that mass would be less than over the eastern half of the lake, where weight and grinding-power must, I believe, on that account have necessarily been greater. But the main flow of the ice, after escaping from the Rhone valley, was necessarily of a mixed nature, partly to the N.W., and also to a great extent to the N.E. and S.W., simply because the N.W. face of the glacier abutted on the Jura. For it requires no profound knowledge of physics to perceive that any body, whether actually plastic like pitch, or of a modified plasticity that may be fractured and reunite like *jelly**, or that by "fracture and regelation" behaves like a plastic body,—I say it requires no profound knowledge of physics to understand that such a body, constantly renewed and pressed on from behind, when opposed by a high impassable barrier (like the Jura), will spread itself out in the direction of least resistance, that direction in the case of the Rhone glacier having been at right angles to the general pressure, or N.E. and S.W., whence I believe the general form and trend of the Lake of Neuchatel.

But, in the second place, is there indeed no proof that ice "neither has nor has had any excavating power," whether in valleys of large or of low inclination, narrow or broad? Then why is it that all the rivers that flow from glaciers, great and small, are so muddy? Surely no one will contend that all "the flour of rocks" that gives to the rivers a pipeclay colour has been washed in by streams from the surface. Alpine club men who drink (rarely) of the brooks that run on the surface of the ice will repudiate the idea; those who fancy they see in the Loess of the Rhine the old glacier-ground mud of the Alps will shrink from it; and many, if not all the Alpine geologists versed in ice whom I have conversed with in Italy and Switzerland, will, I venture to say, still hold that glaciers by erosion seriously affect their beds. What else is the meaning of the striation and deep grooving, the mammillation and the glassy polish, even of quartz, and of all the Alpine rocks, whether hard or soft? The mud of the rivers is chiefly derived from this incessant ice-waste; and that is why it is so *unealthy*, so clean, fresh, and impalpable. Were it merely or chiefly surface-wash, derived from the hills and washed underneath and carried forward below the glaciers, the sediment in great part would be dirty, torrential, and coarse enough, especially if, as is stated, glaciers do not seriously grind along their rocky floors. So far from a glacier exercising only a trifling grinding-power, "because it is usually separated from the subjacent

* I have obtained this comparison from the Master of the Mint.

rock or vegetable soil by water arising from the melting of the ice," the grinding power is so immense, that in unweathered ground comparatively recently covered by a glacier, every foot of surface is often polished and striated. If, indeed, water usually separates ice from the rock so that it does not press upon it, a glacier, whether 30 or 3000 feet thick, would need to be treated in the main as a floating body; and it is well known that with floating ice there is some eight or ten times as much ice below as above the water.

As for bosses "still standing out in the midst of the valleys" proving that glaciers have no erosive power, the reader unlearned in theories of denudation will easily understand that the same kind of argument might be applied to the pillars of earth left for a time in the midst of a railway-cutting the actual excavation of which he had not seen; or because Goat Island still stands in the middle of the falls, the Niagara has not cut its gorge; or because other low islands lie higher up, the river has not worn out a channel on either side of them and will not destroy them; or in marine denudation, that the chalk between Old Harry and his Wife and the mainland of Swanage Bay, and that between the Needles and the Isle of Wight, has not been washed away by the sea, because the islets still stand in the midst. If, however, it be said that the glacier-islets are the result of old subaërial denudations before the glacier began to flow, I might perhaps doubt it, but, for evident reasons, for the purpose of this argument, I will not quarrel with it. If they have not been left prominent either by streams or ice, then, according to the hypothesis which accounts for these valleys by disturbance, the bosses in the midst of the glaciers are the result of a process of dislocation of which I should like to see the special proof.

The peculiarity and in part the amount of this wearing action of ice is indeed due to that very "plasticity" which enables ice to mould "itself upon the inequalities of the hard rock." And it is just therein that its excavating power differs from that of water. Still water cannot excavate a large basin-shaped hollow, and in the depths of a lake water is still; but glacier-ice, having "moulded itself upon the inequalities of the hard rocks over which it passed," can even move right over a barrier of rock and grind it into *roches moutonnées*. The very fact that a *roche moutonnée* has, as stated by Sir Roderick, a "*Stoss-Seite*," is indeed proof that with sufficient pressure behind, a glacier can to some extent pass uphill; and those who remember the great size and height of many of these barriers in Switzerland, as, for instance, the Kirehet and the hill behind the Grimsel, will be prepared to follow the arguments urged in my original paper—and, for dif-

ferent reasons, also held by De Mortillet—viz. that a glacier of sufficient thickness could not only fill a lake, but could flow up the low angle of the ascent towards the outflow and escape beyond its bounds*.

If a glacier can round, polish, and cover with striations the rocks over which it passes—if, flowing from its caverns, it can charge rivers thickly with the finest mud, then it can wear away its rocky floor and sides. Here indeed an appeal to nature may safely be made, and the answer will be easily obtained; for, standing on the surface of scores of glaciers, such as those of the Aar, and casting the eye upward, the whole mountain-sides are *moutonnés*, and parallel striations running along and down the valley are universal; and not there alone, but miles and miles below the end of the puny glaciers of today the signs of the same wearing actions of grander ice-streams are visible both in and thousands of feet above the present bottoms of the valleys. It needs no subtle argument to prove it. Nature proclaims it; we have but to open our eyes and look upon it to see that ice grinds, and has ground and planed away the surface of rocks, as surely as a planing machine cuts iron, and for much the same cause. "What more," says Hutton, writing of analogous waste, "what more is required? *Nothing but time*. It is not any part of the process that will be disputed†; but after allowing all the parts the whole will be denied; and for what? only because we are not disposed to allow that quantity of time which the ablation of so much wasted mountain might require." "TIME," says Playfair, "performs the office of *integrating* the infinitesimal parts of which this progression is made up;" and though I have in this Magazine formerly attempted to show, for purely geological reasons, that the greater valleys in the Alps existed before the so-called glacial period, yet I know perfectly well, not only that since that time glaciers have worn a vast quantity of matter out of them, but that, given sufficient time, a glacier of itself might scoop out a valley of any depth, just as running water may do the same, or as surely as that, given sufficient time, the sea will wear away any island, soft or hard, large or small, that rises amidst its waves.

In further proof of the assertion that glacier-ice can have no serious effect in wearing away its bottom, great stress is laid on the well-known fact that such short and steep glaciers as those

* Unless I am much mistaken, geologists will some day be much surprised at the size and kind of hills that they will be obliged to allow that glaciers have travelled over.

† Things, however, that he considered almost self-evident are now disputed every day. The tendency of opinion begins to set in the opposite direction.

of the Brenva and Miage ride over their moraines. I know these glaciers well, and the statement that they do ride on their moraines is perfectly true; but few geologists, and probably no physical philosopher will rest his reputation on the assertion that, if those glaciers were to increase till they attained their ancient size, when as mere tributary sources they helped to swell the enormous mass that ploughed all down the Val d'Aosta to beyond Ivrea,—will anyone, I say, rest his reputation on the belief that these moraine heaps would lie where they now do, underneath a thousand or thousands of feet of ice, unmoved to all eternity, or at least till the complete decline of the glaciers permitted the loose material to be attacked by running water? If so, again, whence the muddy glacier rivers, and whence the scratched stones that come *from under* the glaciers? Tyndall will not believe in their immobility, nor De Mortillet, nor Gastaldi, nor Darwin, who was the first to show that the larger glaciers of Wales had ploughed the drift out of some of the greater valleys of the country; and many other geologists of weight will equally shrink from the idea. Has ice no weight? Do the huge glaciers of Victoria-land and of Greenland exert no pressure on the ground over which they flow? and are there no stones and no powder of rocks beneath to help the grinding-power? Rub iron with your finger often and long enough, and it will wear a channel in the metal; for the skin, like the passing glacier, will be renewed, while the iron has no means of restoration. If yielding water can wear out a channel, which few people will deny, far more, then, must the weight of a thick glacier exercise a prodigious abrading-power; for surely no one on reflection will be so bold as to assert that 50 feet, or one, two, or three thousand vertical feet of ice with a specific gravity of nearly 0.92 will everywhere, or nearly everywhere, be separated from its floor by a stratum of water so complete that the glacier rarely touches the bottom. If Agassiz, Forbes, and Tyndall, backed by Studer, Escher, and Gastaldi, were to tell me so (and they would not dream of it), my reverence for authority (and it is great) could not persuade me to believe them.

If, then, glaciers can waste rocks and deepen valleys, is it possible that the great old glaciers under favourable circumstances have excavated lake-basins, when rocks of unequal hardness came in their course, or when from special causes the pressure of ice was unusually great on certain areas? Or were they apt to do so by a combination of these causes, when, ceasing to flow through valleys of great or of moderate inclination, they descended into regions that are comparatively level?

I will not repeat what I have elsewhere printed about the effect of ice passing over rocks of unequal hardness, nor yet what

I have said of the confluence of immense glaciers like those that once united in the valley of the Lago Maggiore at what are now the Borromean Isles. But it seems to me that to any one who allows any excavating power to a glacier, it will be evident that when the general inclination of a valley was comparatively steep, a glacier could have had no opportunity of cutting for itself any special basin-shaped hollows. Its course, with a difference, is like that of a torrent. But in a flat-bottomed part of a valley, or in a comparative plain that lies at the base of a mountain-range, the case is not the same. For instance, to take an extreme case, if a glacier tumble over a slope of 45° , no one would dream of the ice-flow producing any special effect, except that in the long run, the upper edge of the rock that forms the cataract being worn away, its average angle would be lowered. And so of minor slopes; if the ice flowing fast (for a glacier) rendered the rocky surface underneath unequal, such inequalities could not become great and permanent; for the rapidly flowing ice would attack the projecting parts with greater power and effect than the minor hollows, and so preserve an approximate uniformity, or an average angle of moderate inclination. But when a monstrous glacier descended into a comparative plain, or into a low, flat valley, the case was different. There, to use homely phrases, the ice had time to select soft places for excavation, and there, if, from the confluence of large glaciers, or for other reasons, the downward pressure of the ice was of extra amount, the excavating effect, I contend, must have been unusually great in special areas, and have resulted in the formation of rock-bound hollows. And though the glacier of Ivrea has been constantly quoted as a case that completely proves the absurdity of my theory, this merely shows the unwariness of those who quote it; for not only are there a great many rock-basins full of water above Ivrea in among the vast *roches moutonnées* near the opening of the plain, but, where beyond this point the glacier spread out so wide on the Pliocene plain, it has scooped away so much material that parts of that plain are below the average level of the plains of Piedmont that lie outside the great moraine. Given sufficient time and extension of the glacier, and more matter still would have gone away. The same argument equally applies to the case on the Lake of Zurich, where glacier débris is said to lie on alluvial detritus. In reply to the question why in the actual valley of Aosta there are no lake-basins, I might with equal propriety say, Many contorted regions are much faulted, and there is often an evident connexion between contortion and faults; but in some contorted regions there are few or no faults, and the reason of their absence remains to be accounted for. I have attempted to explain why the rock-basins are present, and not

why they are absent. It may be that some of the alluvial flats of the valley are lake-hollows filled up.

But another statement urged by Sir Roderick against my theory is, that the scooping-out of such hollows by ice is impossible, because ice cannot flow up an inclined plane. If so, I repeat, what is the meaning of the "*Stoss-Seite*" or upper side of a *roche moutonnée* that bars a wide glacier valley, through which barrier perhaps a mere narrow river gorge passes—as, for instance, in the case of the Kirchet so well known to Alpine men, or, on a smaller scale, of the *roches moutonnées* near the slate-quarries in Nant Francon? In both cases the barrier remained intact till the drainage of the glacier-formed lakes cut gorges through them—or, if Sir Roderick prefer it, till convulsions made gorges. Its *moutonnée* form will convince every accomplished glacialist that the ground was once covered by ice. The strike of the rocks will be enough for ordinary geologists; for no man can suppose who sees the corresponding forms of the *roches moutonnées* on either side of the narrow gorge of the Aar, that that gorge existed before the period of the great glacier, and that the glacier flowed entirely between the walls of the narrow passage. If I am right in this, then the great old glacier of the Aar flowed right over the hill, from bottom to top, and away into regions far beyond, in the manner I have imperfectly shown in my little book on the old glaciers of Switzerland and North Wales, and equally so whether the gorge was formed by sudden violence or by water.

In the existence, therefore, of "*Stoss-Seiten*," and in their upward striations, both in small and large *roches moutonnées*, there is proof that the belief that glaciers cannot flow over hillocks, and even hills of considerable size, is a mere assertion founded on prejudice: to me the wonder is, that any one can ever have believed it who has truly observed phenomena in the Alps, or who is familiar even with the ancient glaciation of our own country. And if this be so, I see no difficulty in accepting the hypothesis that the length and inclination of the slope which the bottom of a glacier may ascend depend simply on the thickness of the ice, and on the amount of the propelling power behind, that power being due to the weight and mass of the descending ice, and the average angles of the valley behind the point whence the upward ascent begins*.

Now, in dealing with this question, most of the geologists who have opposed me have treated the larger lake-hollows much as they do *Time*. Unconsciously they seem to me to be afraid both of it and of them. "Look," they seem to say, "at these mountains,

* I think it might be possible to make a very good approximate calculation on this point, and I hope it may yet be done.

how awfully high and rugged they are ; can any amount of time, aided by weather, torrents, rivers, and glaciers produce such effects? Old writers, like Hutton and Playfair, and a few modern observers (some of whom, both in America and Europe, have great familiarity with rocks), say they can; but we know that rending and fracture is the chief agent, and denudation is in comparison quite a trifling affair. Look, again, at the hollows of the lakes, how awfully deep they are ! How is it possible for a glacier ever to have slid up a hill from a depth so profound?" In treating *the slopes as great*, consists the viciousness of this supposed argument. Unconsciously, some of the arguers are drawing exaggerated diagrams in their minds. They foreshorten the slope, increase in their mind's eye its steepness, and forget their trigonometry altogether. But let me beg of them to try to realize the real state of the case, and see how small by comparison the depth really is, and how gentle the slope. Were the bottom of the Lago Maggiore not undulated (for I believe the islands to be mere *roches moutonnées*), this slope from the deepest part of the lake (2600 feet) to its outflow would only be $2^{\circ} 21'$ in a distance of about 12 miles, a slope so gentle that, were a man standing on it, by the eye he would barely be able to tell whether he was on an inclined plane or not*. Again, take the Lake of Geneva from the place where it is nearly a thousand feet deep to Geneva, the average slope is only about $25'$, an angle so small that any geologist looking at it would be apt to consider the surface as horizontal. The question, then, as regards the lakes resolves itself into this: Is it possible that the ice of the great old glaciers could ever have travelled up these exceedingly small inclinations for a distance, say of 12 miles in the one case and 20 to 25 miles in the other?

And now, in connexion with this point, I could wish that Sir Roderick had expressed an opinion whether or not he agrees with the old geologists, that (p. 7) "the Lakes of Geneva and Neufchatel were so filled up with snow and ice that the advancing glaciers travelled on them as bridges of ice, the foundations of which occupied the cavities." If this were so, then, in other words, the lower strata of ice in the hollow of what is now a lake remained in a condition of static equilibrium, and over this ice the advancing part of the glacier slipped or was propelled. Strictly speaking, it is evident that this state of static equilibrium is impossible; for all the ice of a glacier a little below the surface being, even in winter, in a melting state, the lower strata above alluded to must have been destroyed and renewed over and over again; and as glacier-ice is practically anything but a

* In my original paper on the glacial excavation of certain lakes, I made an unfortunate error in calculation, stating that the angle is about 5° . In an able article in the 'Reader,' Professor Jukes corrected the error, and made the slope 2° .

rigid body, I think it would be easy to show that, just as in Arctic regions in winter the more rapid flow of the lower strata of ice, with a temperature of about 32° , shatters the more rigid and slowly-moving upper layers which have a temperature far below that point, so, for other reasons, the motion of some 2000 vertical feet of ice sliding over the basin, would be communicated to the lower strata; for pressure in ice produces adhesion of parts. I for one cannot conceive a horizontal fracture of 40 miles in length over the area of the Lake of Geneva, clearly dividing two bodies of ice, the lower of which was, where thickest, nearly 1000 feet, and the upper and sliding stratum must have been nearly 3000 feet thick. It is, in fact, a piece of mere elementary knowledge that any heavy body passing steadily across any other body, the parts of which are moveable, will communicate motion to the parts over which it passes, whether one or both of those bodies be viscid or plastic, or of some other compound character; and when I wrote my original paper it never occurred to me that there was any need of mentioning a point so obvious. But in a glacier that fills a lake-basin, this is by no means the only, and perhaps not the principal, cause of motion. A glacier does not throughout all its course move on simply by virtue of gravity. Pressure from behind has a great deal to do with it; as, for instance, in the case of the Rhone glacier, familiar to so many, and cited by Professor Merian and Dr. Tyndall. There, at the cataract, the ice fractures and slides down comparatively rapidly in masses, but at the base, where it moves slowly, pressure from behind causes the masses to touch and reunite, and the whole slides on, a re-formed mass, into the lower valley, the inclination of which is small. So, in the case of the lakes, the depths of which seem so appalling, but the real angles of the beds of which are so small, there seems to me nothing either impossible or remarkable in the idea that the long and enormous onflowing inclined mass of the glacier of the Rhone pushed before it in the plain (for such it is) its own more sluggish continuation up a slope of $25'$ for a distance of 20 or 25 miles. I believe that the same argument is equally applicable to the Lago Maggiore, where the already vast glacier, swelled by the mighty tributary of the Val d'Ossola, was thus enabled to push along the low average slope of $2^{\circ} 21'$ for a distance about half as great. The very islands in many a lake once filled with ice help to prove this; for, as in the case of Loch Lomond, they are mere *roches moutonnées*, and I for one cannot conceive that the mammillation ceases immediately below the surface of the water.

Having got thus far, I will not repeat my arguments to show that (as I attempted to prove in my original memoir) the Alpine and other ice-worn lakes known to me do not lie in areas of *special subsidence*, nor in *gaping fractures*, nor in simple *synclinal*

basins, nor in *hollows of watery erosion*. If any one who reads this is curious about them, he must refer to that memoir*; but this at least I may be permitted to say: I used at all events arguments, even somewhat elaborate, and not mere statements, and whether these arguments are fated to be successful time alone will show. That they were at all events of some value, the names of the distinguished geologists who have accepted my theory helps to show; and I could add to these other names as high as the very highest of those on whose authority Sir Roderick so much depends, did propriety permit me to quote from letters and commit men to opinions which they have not expressed in print.

But before leaving the subject, let me say a little more about the possibility of these lakes lying in fractures. For this purpose let us take some of those that lie on the north side of the Alps, partly in the region of the Miocene strata. If they lie in lines of gaping fracture, nearly as wide as the present lakes, then on the hills, say between the Lake of Lucerne and Thun, and between Thun and the Lake of Zurich, the Miocene strata *would be crumpled up in zigzag lines across the average line of strike, to an amount corresponding to the distance between the severed strata in the spaces now overlooking and occupied by the lakes*. This is not the case. Again, if the fractures were mere narrow cracks, then the amount of denudation that took place so as to form the wide valleys has been enormous, and within a mere fraction of what I require, especially when we consider that the great denudation necessary to widen the fractures would have filled up the lake-basins. The theory of the chief formation of Alpine valleys having been effected by weather, water, and ice, would therefore still hold good.

I might continue these arguments, and discuss in detail what Sir Roderick has said about Scandinavia, North America, and other regions, and among other things show how unprecise is the knowledge that we actually possess respecting the details of the boulder-beds that overspread some of them, and how unsafe it is to conclude, because a country is not actually mountainous, and does not now lie high above the sea-level, that it was never covered by glacier-ice in motion, and may not at one time have lain much higher. In spite of Agassiz's memoirs, it is not long since all the lower Till of Scotland was considered not to be ordinary moraine-matter at all, but to have been formed solely in the sea by the transporting agency of icebergs. Let those who still believe it refer for proof to the contrary to Mr. Geikie's admirable work 'On the Phenomena of the Glacial Drift of Scotland.' I know enough of the superficial strata in North

* They are also given in 'The Physical Geology and Geography of Great Britain.'

America to foresee that the erratic deposits there will some day also be divided into terrestrial and marine series, and I am pretty sure that Sir William Logan will not deny the probability. For the vast size of the ancient glaciers of that continent, I would refer to Professor Dana's admirable *Manual of American Geology*. It is a mistake to suppose that the striations there merely run from north to south, for Sir William Logan, who has mapped them, proves that they often conform to the bends of the valleys.

As regards the great lakes of that continent, so far from being "cavities originally due to a combination of ruptures and denudations of the rocks," it is impossible intimately to know the country and believe it. There the Silurian strata, amid which the lakes lie, are arranged so tranquilly and at angles so low, that the flattest chalk of Great Britain may be almost said to be tumultuous in comparison; and the forthcoming sections of Sir William Logan conclusively prove that around the lakes there is no trace of dislocation to help to form the hollows, nor yet do they lie in hollows of special subsidence. Only Lake Superior covers a faint synclinal curve; and Lake Ontario, so far from occupying an area of special depression, actually lies on a very low anticlinal bend of soft strata, the top of which has been denuded away. That Sir William, who has been called the best stratigraphical geologist in America, believes that ice has something to do with the scooping out of rock-basins, any one may see who refers to his late masterly report on the geology of Canada; and Professor Newberry, whom Sir Roderick knows as a physical geologist and geographer, adheres strongly to that opinion.

As for the observation of my friend M. de Verneuil, that the orographic hollows in Spain are precisely those that "a theorist" might "attribute to excavation by ice," I decline to be judged by it, till I have seen them and declared that opinion. I object, both for myself and my supporters, that we should be judged in a manner so vague. And further, I think I appeal to Nature to some purpose when, neither for the first nor the second time, I ask philosophers to consider why it is that not only drift- and moraine-dammed lakes, but striated rock-basins of all sizes occur in such prodigious numbers in America, Scandinavia, the Highlands, and in all other rocky temperate regions, high or low, that have been glaciated, while in tropical and subtropical regions they are so rare as to be quite exceptional elsewhere than in mountain areas that now or once maintained their glaciers.

Several other points raised by Sir Roderick in that part of his Address that relates to physical geology, glaciers, and icebergs remain to be discussed. I have entered, however, on this argument with great reluctance, and, unless circumstances again constrain me, I shall leave the remaining questions untouched.

